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# Impact of non-axisymmetric magnetic field perturbations on flows

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## Introduction

- Plasma rotation plays a key role in plasma confinement [1][2];
- Control of plasma rotation in reactor-sized tokamak is challenging [3];
- Intrinsic bulk plasma rotation is driven by turbulence and **Neoclassical Toroidal Viscosity (NTV)**;
- Magnetic field ripple is responsible for the NTV.

**Objective:** Understand the competition/synergy between turbulence and NTV with gyrokinetic simulations.

## Theoretical model

A reduced model based on the mean toroidal velocity  $V_T$  reads :

$$\frac{\partial V_T}{\partial t} = \text{Neoclassical Toroidal Viscosity} + \text{Turbulent torque}$$

Ripple constrains  $V_T$  through neoclassical friction  $v_\phi$

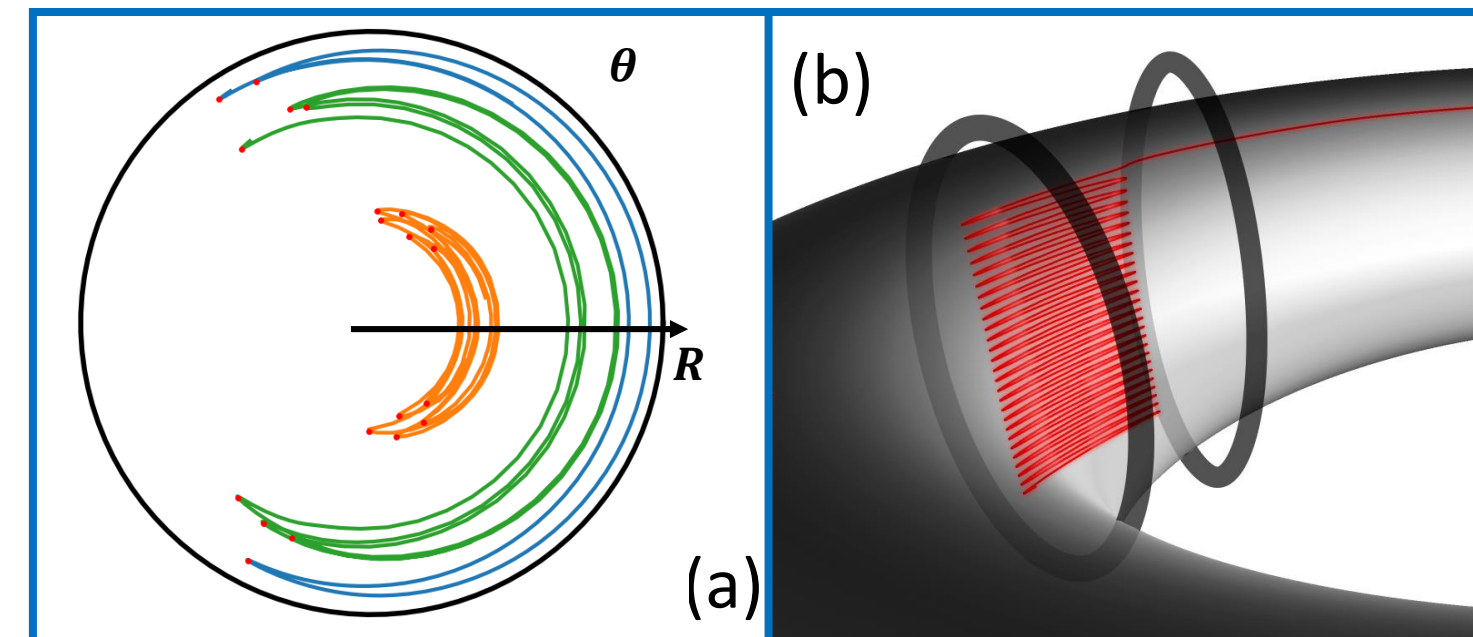


FIG.1 – Kinetic effects induced by ripple : drift of banana bounce points (a) and toroidal trapping between coils (b). Neoclassical friction  $v_\phi$  comes from the collisions between trapped populations.

Turbulence constrains  $V_T$  through turbulent viscosity  $\chi_{turb}$

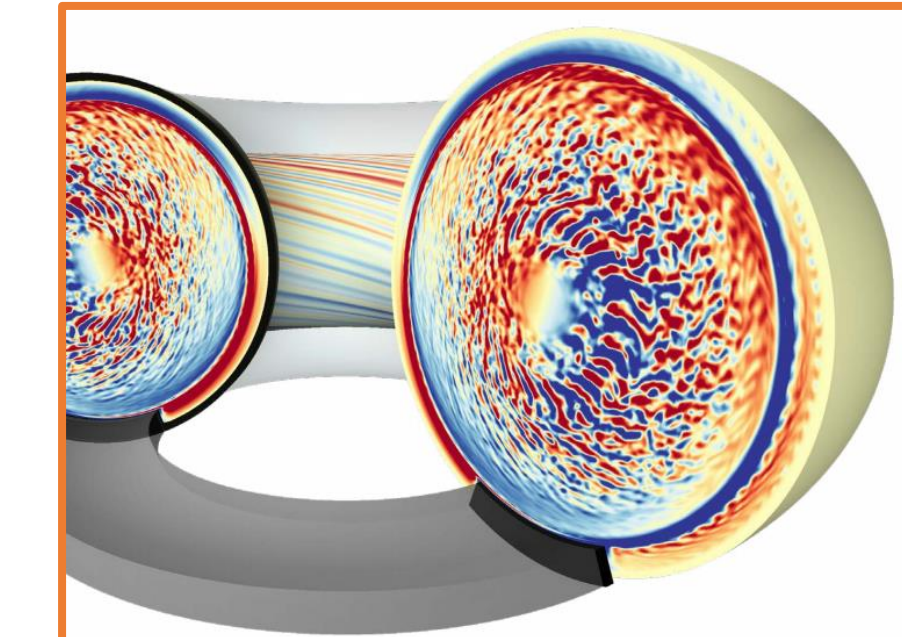


FIG.2 – Snapshot of the turbulent structures seen through a colormap on the electric potential. From rest,  $V_T$  grows due to wave-particle interactions.

**Goal:** Obtain coefficients of **turbulent momentum transport from simulations** and use **neoclassical friction  $v_\phi$  predictions** to find the ripple amplitude threshold for which **neoclassical effects overcome turbulence**.

## Turbulent momentum transport

Turbulence impacts  $V_T$  through the toroidal Reynold's stress  $\Pi_\phi$

$$\Pi_\phi = \underbrace{-\chi_{turb} \frac{\partial V_T}{\partial r}}_{\text{Viscosity}} + \underbrace{\mathcal{V} V_T}_{\text{Pinch}} + \underbrace{\Pi_{res}}_{\text{Residual}} \quad (\text{Eq.1})$$

Obtention of  $\chi_{turb}$ ,  $\mathcal{V}$  and  $\Pi_{res}$  using gyrokinetic simulations :

- Simulations of turbulent plasma without ripple with different initial toroidal velocity  $\rightarrow$  FIG.3 shows the dominance of the viscosity :  $-\chi_{turb} \frac{\partial V_T}{\partial r}$ ;
- Eq.1 defines a plane in the  $(V_T, \partial_r V_T, \Pi_\phi)$  space;
- Mean square plane fit using simulations output gives an estimation of  $\chi_{turb}$  within a radial range (see FIG.4 for an example).

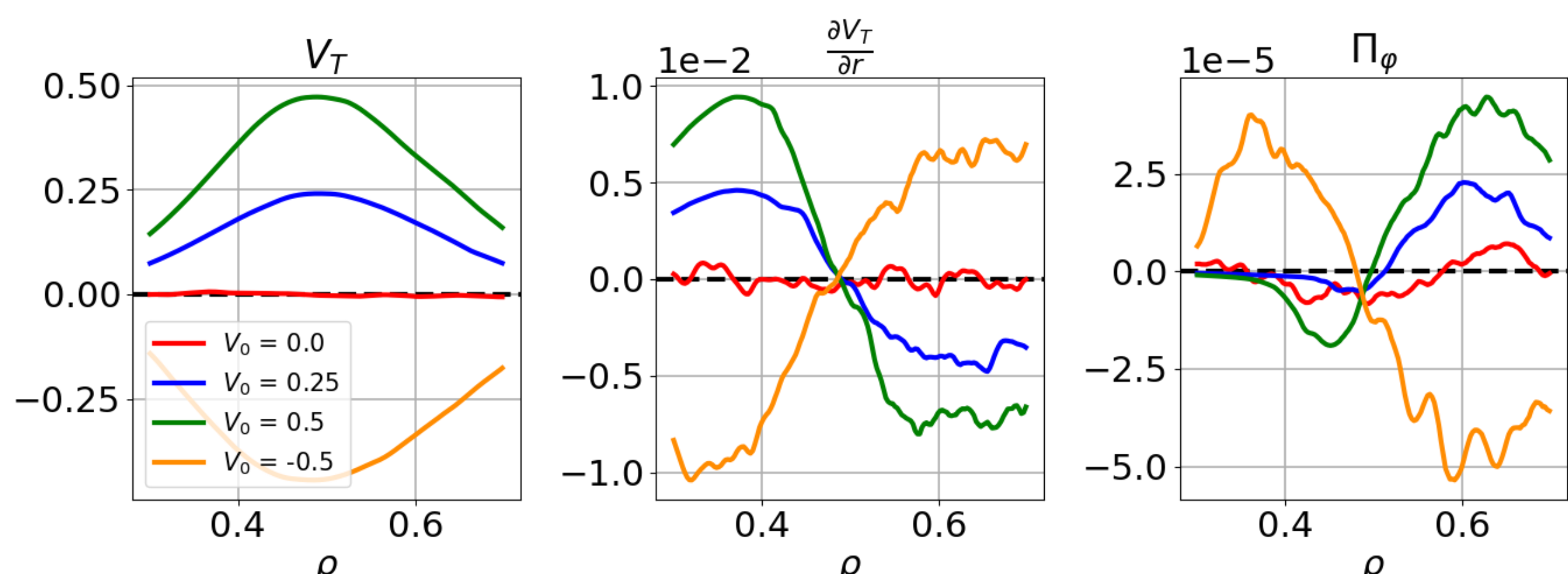


FIG.3 - Radial profiles of  $V_T$ ,  $\partial_r V_T$  and  $\Pi_\phi$  taken at turbulent saturation for simulations initialized at different toroidal velocity  $V_T(t=0) = V_0 e^{4(\rho-0.5)^2}$

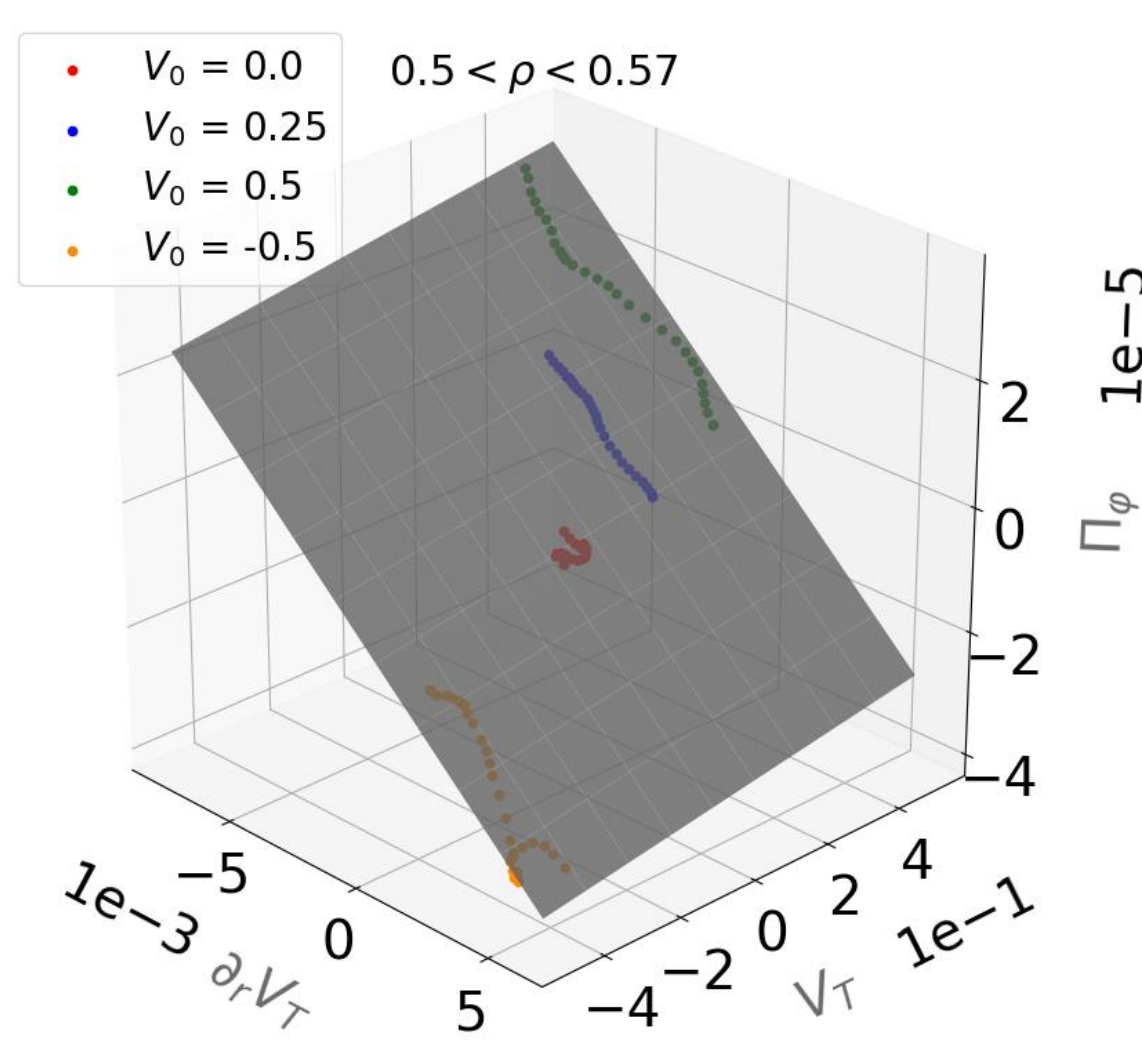


FIG.4 - Plane fit of  $\Pi_\phi$  using point cloud from simulations giving an estimation of the turbulent viscosity within a radial range.

## Neoclassical friction

- Ripple is responsible for magnetic braking  $m$  in the toroidal direction : the NTV;
- Neoclassical theory [6][7] with ripple gives :

$$m = -v_\phi \left( V_T - k_T \frac{\nabla T}{e B_p} \right)$$

$\downarrow$  Friction
 $\downarrow$  Thermal drive

- GYSELA code shows good agreement with neoclassical predictions;
- $v_\phi$  increases with the ripple amplitude.

## Conclusion

- Ripple is responsible for a neoclassical friction that constrains the toroidal velocity;
- Turbulence is a source of intrinsic rotation;
- Evolution of mean toroidal flow ruled by competing turbulent stress and ripple drag forces;
- The radial electric field grows in response to the modification of the toroidal velocity;
- Simulations suggest that neoclassic drag overcomes turbulent stress for typical realistic ripple amplitudes in WEST;
- Future work taking into account boundary physics with realistic WEST ripple amplitude is necessary to understand the shape of  $\frac{dE_r}{dr}$  and the transition toward high-confinement modes.

## Competition ripple/turbulence

Complete model reads :  $V_T$  relaxation time

$$\frac{\partial V_T}{\partial t} \approx m - \nabla \cdot \Pi_\phi \Rightarrow \tau_V \sim \max \left( \frac{\chi_{turb}}{L_V^2}, v_\phi \right)^{-1}$$

$V_T$  gradient's length

Boundary physics not in the model  $\rightarrow$  radially gaussian ripple (cf FIG.5)

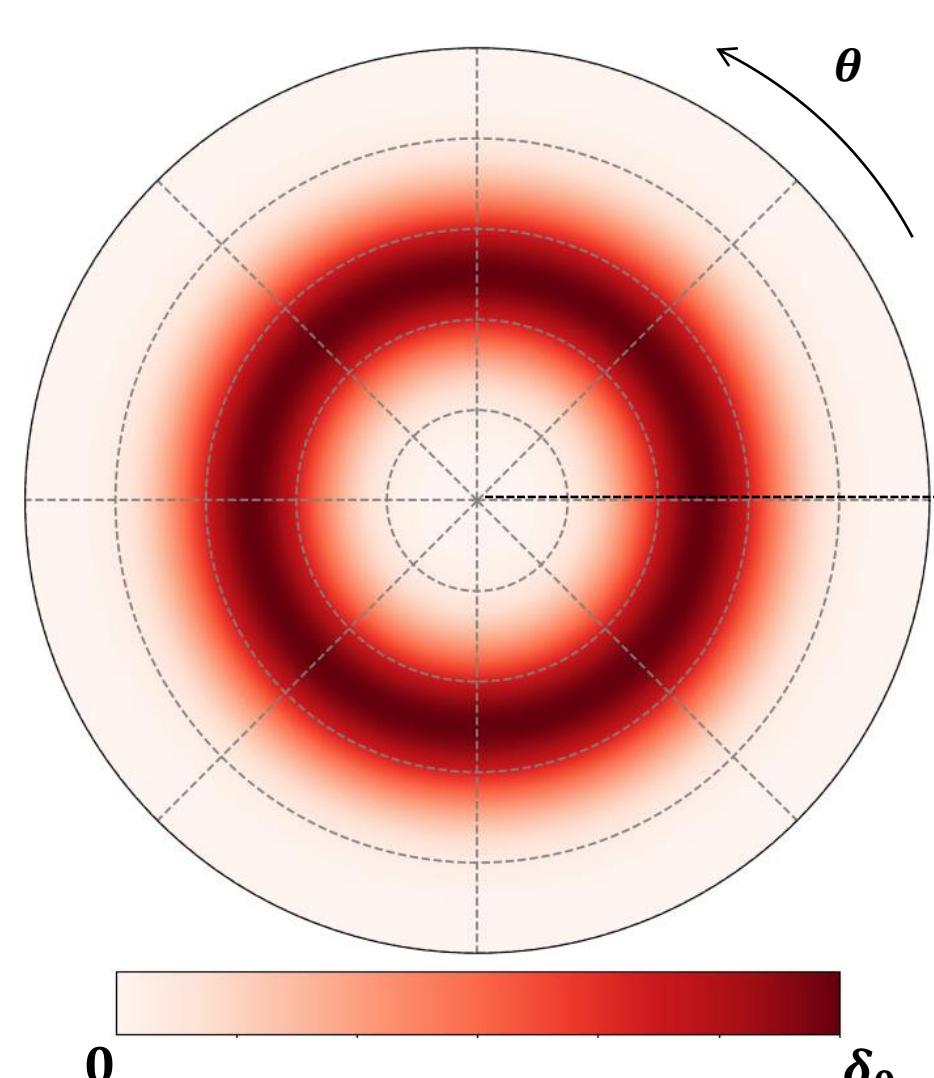


FIG.5 – Polar map of the ripple amplitude used for simulations.

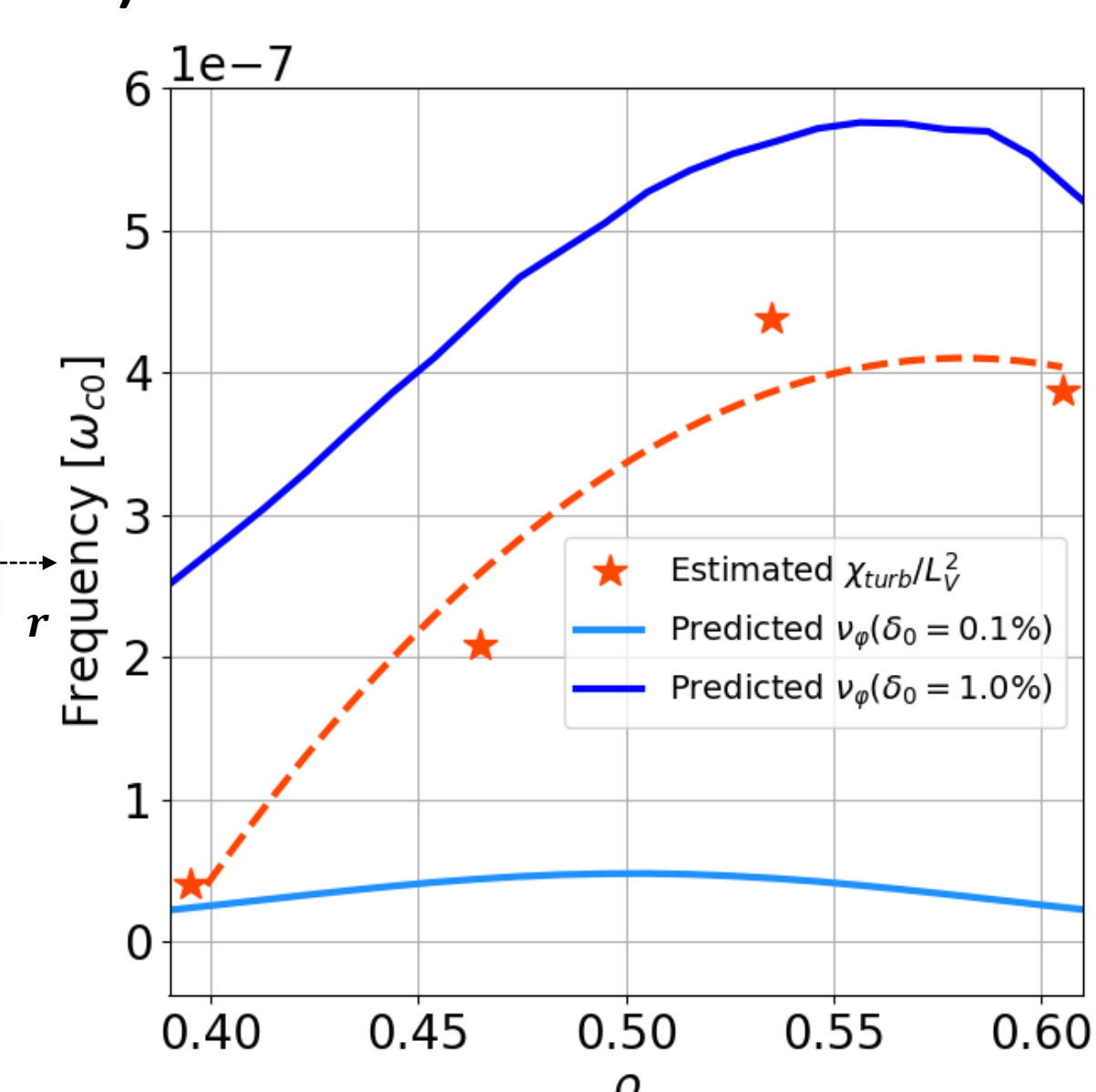


FIG.6 – Radial profiles of estimated turbulent relaxation frequency and predicted neoclassical frictions.

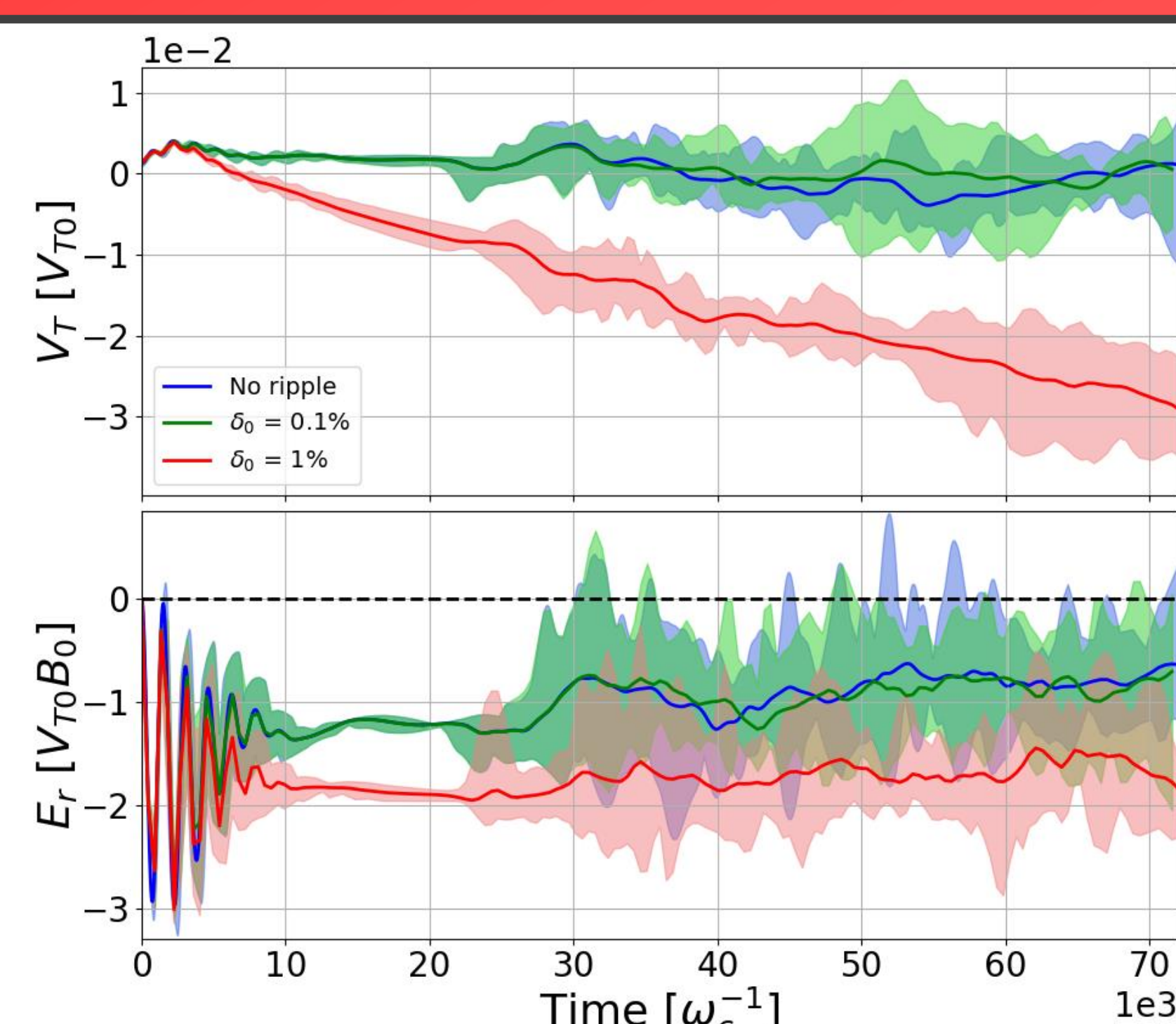


FIG.7 – Time evolution of  $V_T$  and  $E_r$  in the range  $0.45 < \rho < 0.55$  for different ripple amplitudes.

Model verification using 2 simulations :

- With dominant neoclassical friction
  - With dominant turbulent viscosity
- See FIG.6

Main result FIG.7

- $\delta_0 = 0.1\%$  case dominated by turbulence
- $\delta_0 = 1.0\%$  case driven by neoclassical friction  $\rightarrow$  increase of  $E_r$  to fulfill force balance

## References

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